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Engineering
With Specialization in Construction Technology and Management

Modeling compressive strength from non-destructive test results

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CHAPTER I

Problem Setting

1.1 Background of the Study

1.1.1 Historical background

Concrete is the most widely used structural material for construction today. Traditionally, concrete has been fabricated from a few well-defined components: Cement, water, fine aggregate, coarse aggregate, etc. In concrete mix design and quality control, the strength of concrete is regarded as the most important property. Many other properties of concrete, such as elastic modulus, water tightness or impermeability, resistance to weathering agents, etc. are directly related to the strength. The compressive strength of concrete is many times greater than other types of strength, and a majority of concrete elements are designed to take advantage of the higher compressive strength of the material. Most often, an ultimate target in the mixture design is the 28th day compressive strength. The 28th day compressive strength is usually determined based on a standard uniaxial compression test and is accepted universally as a general index of concrete strength. The compressive strength of concrete is related to mix proportions and mix

preparation techniques, but the result of the compression test of a specimen can be influenced by the shape, dimension, and the boundary conditions of the specimen. Traditionally, concrete mix is designed based on previous experiences. However, knowledge from previous experiences is limited since all possible combinations of components, proportions, and mixing techniques have not been investigated or published. (Kim et al., 2004)

Non-destructive testing is a technique that allows the investigation of the properties of concrete without needing to damage it.

Durability performance of concrete structures is unfortunately not always as good as anticipated for a variety of reasons. The principal driving force for the numerous developments of non-destructive test methods and equipment has been the requirement of industry worldwide for long-term maintenance strategies. There have been significant advances in equipment capabilities and a range of new techniques related to durability and integrity assessment. These techniques have become established in practice. The troubleshooting and maintenance role of in situ testing remains assured. However, attitudes amongst the engineering community towards in-place testing for quality control during construction remain largely unchanged. This is apart from limited acceptance of testing for strength development monitoring and increased use of covermeters. Cubes/cylinders remain the 'gold standard' for concrete acceptance for the foreseeable future. (Maierhofer et al., 2010)

In 1974, several high-alumina-cement pre-tensioned beams in the UK collapsed because of major loss of concrete strength owing to the 'conversion' of the high-alumina-cement concrete under unfavorable environmental conditions. This led to a nationwide program of inspection and assessment. (Maierhofer et al., 2010)

1.1.2 Motivation of the study

Non-destructive testing is not much used in the Philippines. However, there are local literature for it. (Ongpeng, 2015)

Non-destructive testing also has a problem with regards to the guideline calculations given by the manufacturer. The guideline equation for the use of different non-destructive testing instruments have proven to be inadequate. This is since the conditions of the concrete used in the industry could be different from how the manufacturer have created the concretes used for testing.

Despite the major efforts in producing the British and European Standards, there are notable gaps, especially relating to reinforcement corrosion assessment. (Maierhofer et al., 2010)

Non-destructive testing is a kind of testing that preserves the integrity of the section being analyzed. This is useful since it allows for the concrete strength initially planned to be compared with the current concrete strength. This is useful since the strength of the concrete may not be as promised or would have degraded over time due to environmental factors.

A motivation for modelling the concrete strength comes from the fact that there is much disparity with regards to results from different literature. The figure below shows a part of the discrepancy.

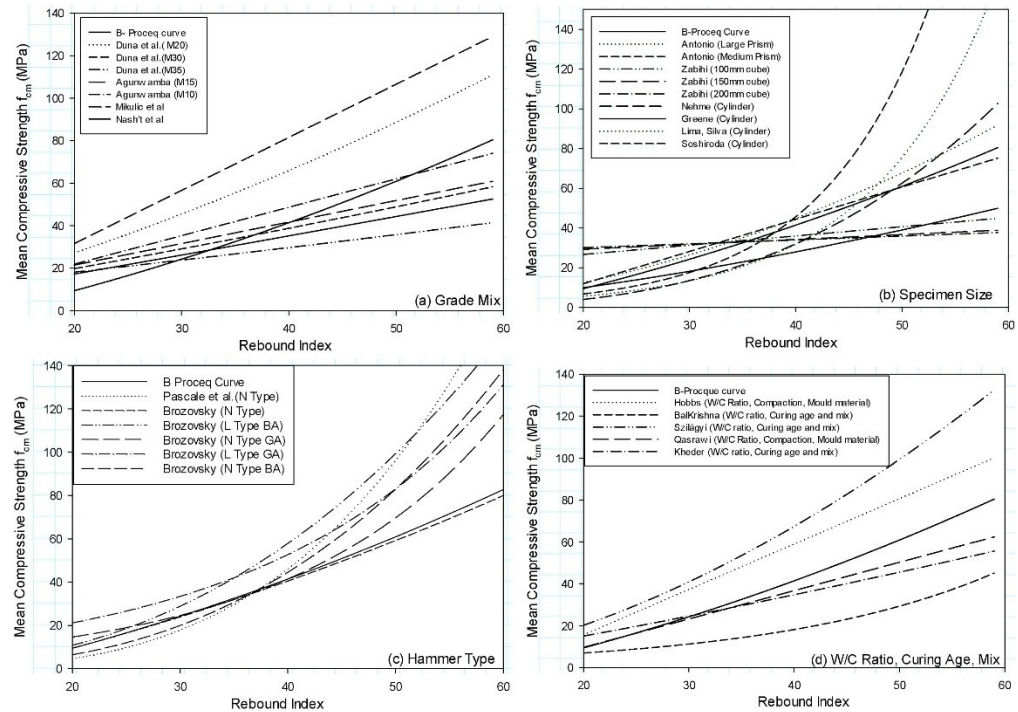


Figure 1.1-1 Rebound index vs. compressive strength relationship curves proposed by different authors considering influencing factors. (Kumavat et al., 2021)

The concept of modelling the compressive strength comes from the utopic vision that if all the factors are considered, then it would be possible to narrow down the causes for the discrepancies in the cuves.

1.1.3 Past research related to the study

Visual testing is probably the most important of all non-destructive tests. It can often provide valuable information to the well-trained eye. Visual features may be related to workmanship, structural serviceability,

and material deterioration and it is particularly important that the engineer is able to differentiate between the various signs of distress which may be encountered. These include for instance, cracks, pop-outs, spalling, disintegration, color change, weathering, staining, surface blemishes and lack of uniformity. Extensive information can be gathered from visual inspection to give a preliminary indication of the condition of the structure and allow formulation of a subsequent testing program. The visual inspection however should not be confined only to the structure being investigated. It should also include neighboring structures, the surrounding environment, and the climatic condition. This is probably the most difficult aspect of the whole structural investigation or any diagnostic works since what appears obvious to one may not be so to another. The importance and benefits of a visual survey should not be underrated. Often the omission of what appears to be insignificant evidence can lead to a wrong conclusion being made. The advantage of a trained eye is best described by Sherlock Holmes when he wrote: *"I see no more than you, but I have trained myself to notice what I see."* (No, 2002)

(Kim et al., 2004) has applied the practice of using neural networks with regards to destructive methods. The current study aims to do things differently by focusing on the non-destructive methods.

1.1.4 Theoretical issues of the study

The study could theoretically have a problem with regards to which parameters should be included. Even with tools such as principal component analysis,

1.2 Problem Statement

There has been an inconsistency with regards to the different curve fitting results that an ultrasonic pulse velocity (UPV) test and rebound hammer test would give. This study aims to solve the problem by looking at different things that were done in performing the experiment and see how the stuff that was done influenced the compressive strength of concrete.

What is intended to be done with regards to non-destructive testing and compressive strength is to look at the different factors that could affect the compressive strength of the concrete.

W/C Ratio	Porosity, Permeability, Cement content
Mix design	Proportions, Specific gravity
Cement type	Chemical composition, Rheology, Grade of cement
Temperature effect	Thermal expansion, Temp. gradient
Exposed heat effect	Exposed surface char.. Heat load
Moisture Content	Range of Humidity, Creep, Shrinkage
Age effect	Curing age, Heat of hydration
Type of hammer	Mould size, Loading condition, N and L Type (spring coefficient)
Carbonation effect	Rate of carbonation,

Figure 1.2-1 Factors influencing the performance of rebound hammer used for non-destructive testing of concrete members Image from:(Kumavat et al., 2021)

The factors that would be investigated mainly involve factors shown in the table above. Other variables that would be used include rebound number and pulse velocity in ultrasonic pulse velocity test.

1.3 Objectives: Main / Specific

1.3.1 Main Objective

To create a model as to how the different factors would influence the compressive strength of concrete.

1.3.2 Specific Objectives

To identify the different starting conditions and results derived from the past literature. This is used to find the parameters that would be investigated.

To create a model based on the data found.

To narrow down the search to factors that significantly contribute to the compressive strength of concrete. This is useful to see which parameters create a significant difference to the compressive strength of concrete.

To compare results from destructive methods with non-destructive methods

1.4 Hypothesis of the Study

The study will create a successful and insightful model to help with the non-destructive testing of concrete.

The study will identify useful criteria to use in finding the compressive strength of concrete.

1.5 Scope, Limitations, & Delimitations

The scope of the test would be the non-destructive methods in finding out the compressive strength of the concrete.

The limitation would be that the study will not look at studies that could not be seen on the internet.

The delimitation is that the study will not focus on the destructive methods for testing concrete.

1.6 Assumptions

The study will assume that the concrete from other studies is prepared correctly, and that the data analysis is correct.

1.7 Significance of the Study

The study would give insight as to what factors are the most significant when it comes to determining the compressive strength of the

concrete.

Moreover, the study considers the different factors that influences the done concrete tests.

Looking at the different influencing factors is important since it allows us to have a better understanding of what initial factors influence the compressive strength of the concrete.

1.8 Operational Definition of the Study

For

CHAPTER II

Review of Related Literature

2.1 Non-destructive testing

To avoid destructive testing, developing reliable predictive models for concrete compressive strength using nondestructive tests (NDTs) is an active area of research. However, many of the developed models are dependent on calibration and/or concrete history (e.g., mixture proportion, curing history, concrete mechanical properties, etc.), which reduces their utility for in-situ predictions.

To this end, ultrasonic pulse velocity (UPV) and rebound hammer (RH) tests were performed on 84 concrete cylindrical samples. Next, compressive strengths were determined using destructive testing on these cylinders, and predictive models were developed using NDT results.

Furthermore, to ensure generalizability to new data, all models were tested on independent data collected from six different research papers. The results support combined usage of UPV and RH in a quadratic polynomial model structure. Therefore, the final model was proposed based on combining models from a threefold cross-validation of the experimental data. This model predicted the independent data with very good accuracy. (Amini et al., 2016)

The rebound hammer test and the ultrasonic device are used in the field of non-destructive tests to determine respectively the compression strength and

the ultrasonic pulse velocity (UPV) in the concrete.

In addition, the influence of several factors on the modulus of elasticity determined by pulse velocity test was investigated. These factors mainly included the age of concrete and the water/ cement ratio. The results showed that the difference between the resistance values obtained by destructive and non-destructive methods decreases with increasing age of concrete. The dynamic modulus of elasticity increases with the curing time of the concrete until the age of three months. In addition, a simplified expression has been proposed to estimate the rebound number from the value of the dynamic modulus of elasticity determined by pulse velocity test. (Malek & Kaouther, 2014)

A system was set up which enabled the continuous measurement of UPV (Ultrasonic pulse velocity) throughout the fresh and hardening stages.

RCA (Recycled concrete aggregate) concrete produced lower strength and UPV values than normal concrete. However, higher surface hardness was obtained for RCA concrete.

Relationships have been established between strength and UPV, covering the period from immediately after mixing and up to 1 day or 28 days. This would enable more accurate assessments of important early age concrete strengths from UPV measurements. It has also been established that UPV measurements can be used to determine concrete setting. (Latif Al-Mufti &

Fried, 2012)

Previous treatment of rubber with NaOH and silane (A-174) did not produce significant changes on compressive strength and splitting tensile strength of composites, when compared to the untreated rubber–concrete composite. On the other hand, from the behavior showed by the ultrasonic pulse velocity with time, one can infer that the addition of rubber decreased this variable, being the effect more notorious when rubber content increased. This was due to the greater volume that rubber occupies, as well as water absorption. It can be concluded that the ultrasonic pulse velocity was relatively independent of particle size and coupling agent employed. (Albano et al., 2005)

Non-destructive testing methods, both simple and combined, are widely used in Romania, especially if they allow the quality control of in situ concrete. From the simple methods, which are also the oldest ones, a particular development was reached by ultrasonic pulse methods based on pulse velocity measurements and to a less extent by superficial hardness methods based on rebound index measurements.

For both these methods there have been norms or recommendations since 1962. In both cases an attempt to increase the accuracy of the method was made by taking into consideration certain data concerning the composition, maturity and curing conditions of the tested concrete (especially humidity). Both methods have the possibility of utilizing the destructive and non-destructive results, obtained on specimens or cores, even if they are small, for increasing the accuracy of the method. Both methods have been applied on different building sites and precast factories, the hardness methods in most cases with

a preliminary, informative aim due to the superficial character of the collected information. (Făcăoaru, 1970)

Initially, concrete was regarded as having an inherently high durability, but more recent experiences have shown that this is not necessarily the case unless durability design forms an integral part of the design and construction process. There is a need to consider all potential deterioration mechanisms at the design stage to select and specify an appropriate concrete mixture from a durability perspective. The prescriptive specification for concrete based on permissible maximum water–cement ratio and minimum cement content has received much criticism in recent years. It may even have inadvertently allowed designers and contractors to avoid having to consider or implement all the available information required for a sound design for durable construction. This includes careful attention to drainage and detailing to minimize the effects of water, which is a key transportation and fueling agent, upon materials. Unexpected maintenance and repairs arising very early in the specified service life of structures has caused enormous financial burdens to clients. The expectation of the owner of a structure is that it will only require very little or no maintenance during its design life. The owners have realized that the cheapest option for constructing a structure may work out to be an expensive option in the long run.

It was found that most NDT methods rely on comparing tested parameters with established correlations. Empirical relationships provided by manufacturers were found to often provide unsatisfactory results. Where

applicable, it is recommended to conduct test-specific correlation procedures for the NDT of concrete. (Helal et al., 2015)

The current trend in the development of non-destructive testing of materials in civil engineering is mainly concerned with the detection of flaws and defects in concrete elements and structures, and acoustic methods predominate in this field. As in medicine, the trend is towards designing test equipment that allows one to obtain a picture of the inside of the tested element and materials. (Schabowicz, 2019)

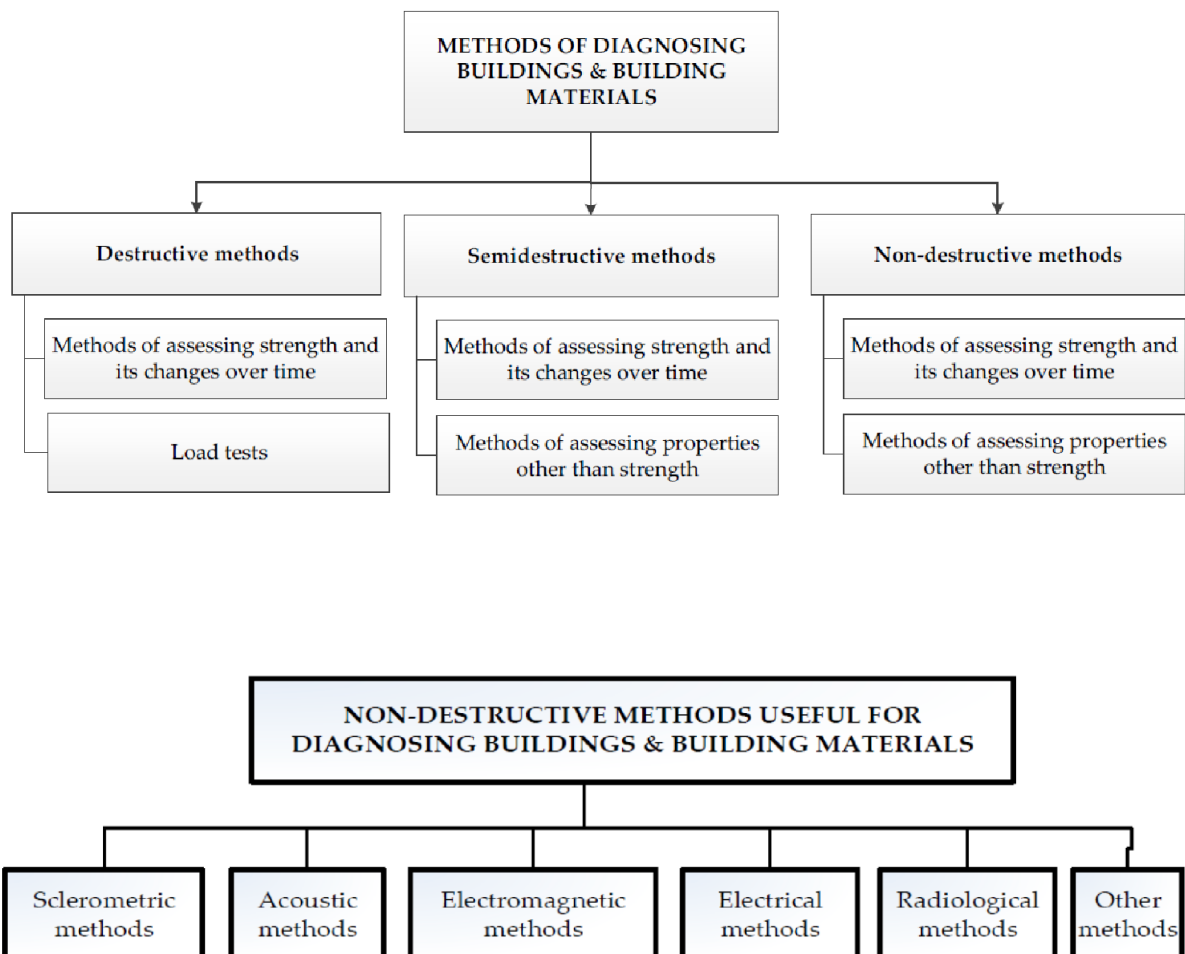


Figure 2.1-1 General classification of non-destructive methods useful for diagnosing buildings and building materials (Schabowicz, 2019)

The main advantage of non-destructive test methods is that they do not damage or affect the structural performance of building components. In addition, they offer simplicity and rapidity in use: test results are readily available on site, the possibility of testing concrete strength in structures where cores cannot be drilled and the application of less expensive equipment. However, too much reliance should not be placed on the calibration curve supplied with the equipment, since the manufacturer develops this curve using standard cube specimens and the mix used could be very different from the one being tested. Both, the impact rebound hammer (IRH) and the ultrasonic pulse velocity (UPV) tests, are only useful if a correlation can be developed between the rebound number/ultrasonic pulse velocity readings and the strength of the same concrete, or at least a concrete specimen with the same composition as the one in question.

Non-destructive testing (NDT) was carried out using ultrasonic pulse velocity (UPV) and impact rebound hammer (IRH) techniques to establish a correlation with the compressive strengths of compression tests. Unlike other works, the research highlights the significant effect of formwork material on surface hardness of concrete where two different mold materials for specimens were used (plastic and wood). A combined method for the above two tests, reveals an improvement in the strength estimation of concrete. The latter shows more improvement by including the concrete density. The resulting calibration curves for strength estimation were compared with others from previous published literature. (Hobbs & Kebir, 2007)

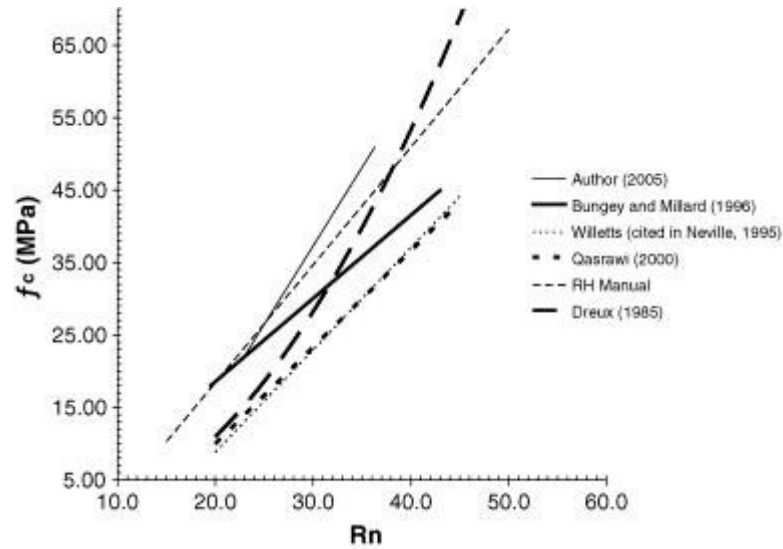


Figure 2.1-2 Comparison of the resulting calibration curve from the IRH test with others from previous research. (Hobbs & Kebir, 2007)

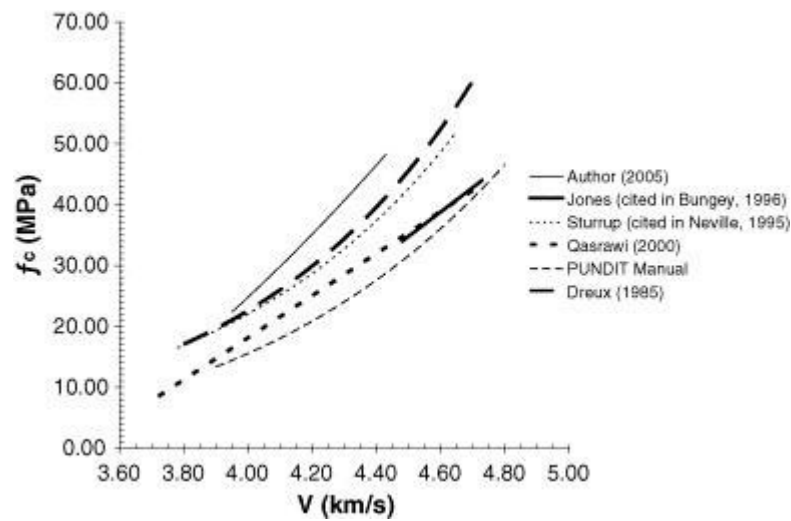


Figure 2.1-3 Comparison of the resulting calibration curve from the UPV test with others from previous research. (Hobbs & Kebir, 2007)

Response Surface Methodology (RSM) is applied to estimate the compressive strength of concrete with more accuracy rather other available models in the literature. The sole NDT and the combination of them are also investigated. The results showed that ultrasonic pulse velocity is the best NDT tests at the beginning ages when it is used in RSM process. (Poorarbabi et al.,

2020)

From the basics of the existing approaches, it is obvious that none of these approaches has the objective to capture the concrete variability although the standards recommend some of these approaches to estimate the concrete variability because it is an essential parameter in the calculation of the characteristic strength of concrete. Thus, we propose here a new “bi-objective” approach which is devoted to capture the variability of concrete strengths in addition to their mean value.

The basic idea is that any investigation program with NDT technique (rebound hammer for example) provides a data set of NC -pairs of (R, f_{core}) , where the rebound measurements and core strengths are measured at the same test locations. This data set is used to identify a relationship (conversion model) between concrete strength and the rebound number test results. Usual mathematical shapes of such models have two parameters. It is the case for the most common ones: (a) linear models $f_{cest} = aR + b$, (b) exponential models $f_{cest} = a \exp(bR)$, (c) power-law models $f_{cest} = aR^b$. Analytically, two conditions are required to derive the values of the parameters a and b . For bi-objective approach, we consider our two objectives as the conditions for obtaining the unknown parameters, i.e., by ensuring that both mean strength and standard deviation are identical for real values and estimated ones:

$$\bar{f}_{cest} = \bar{f}_{core} \quad (2.1-1)$$

$$s(f_{cest}) = s(f_{core}) \quad (2.1-2)$$

Where $\bar{f}_{cest}, \bar{f}_{core}$ are the estimated and measured (on cores) mean

strength values respectively, while $s(f_{cest}), s(f_{ccore})$ are the estimated strength variability and the variability calculated from the core strengths, respectively.

Applying the first condition on a linear model $f_{cest} = aR + b$, we get:

$$\bar{f}_{cest} = a\bar{R} = \bar{f}_{ccore} \quad (2.1-3)$$

while the second condition can be rewritten in the form:

$$s(f_{cest}) = s(f_{ccore}) \rightarrow s^2(f_{cest}) = s^2(f_{ccore}) \rightarrow var(f_{cest}) = var(f_{ccore}) \quad (2.1-4)$$

$$var(aR + b) = var(f_{ccore}) \quad (2.1-5)$$

$$a^2 var(R) = var(f_{ccore}) \quad (2.1-6)$$

Consequently, the values of the unknown parameters are:

$$a = \frac{s(f_{ccore})}{s(R)} \quad (2.1-7)$$

$$b = \bar{f}_{ccore} - a\bar{R} \quad (2.1-8)$$

Where $\bar{R}, s(R)$ are respectively the mean and standard deviation values of R test results corresponding to the core locations.

The bi-objective approach is presented here with the rebound hammer as NDT technique. However, the same principles remain valid for other NDT techniques such as the ultrasonic pulse velocity. This is because in the above development of the parameters (a and b) there are no constraints related to the type of NDT approach.(Alwash et al., 2016)

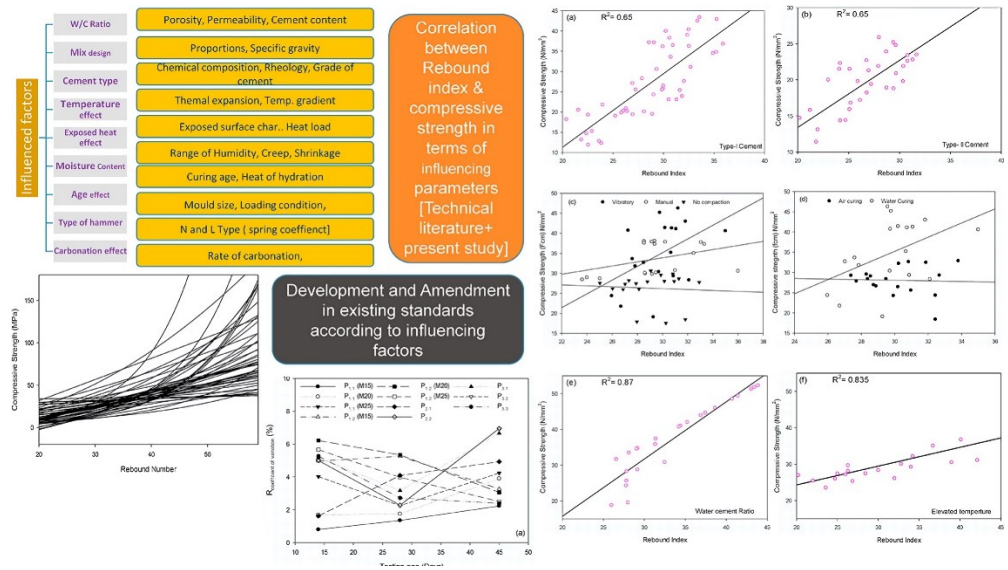


Figure 2.1-4 Graphical abstract of Factors influencing the performance of rebound hammer used for non-destructive testing of concrete members: A review(Kumavat et al., 2021)

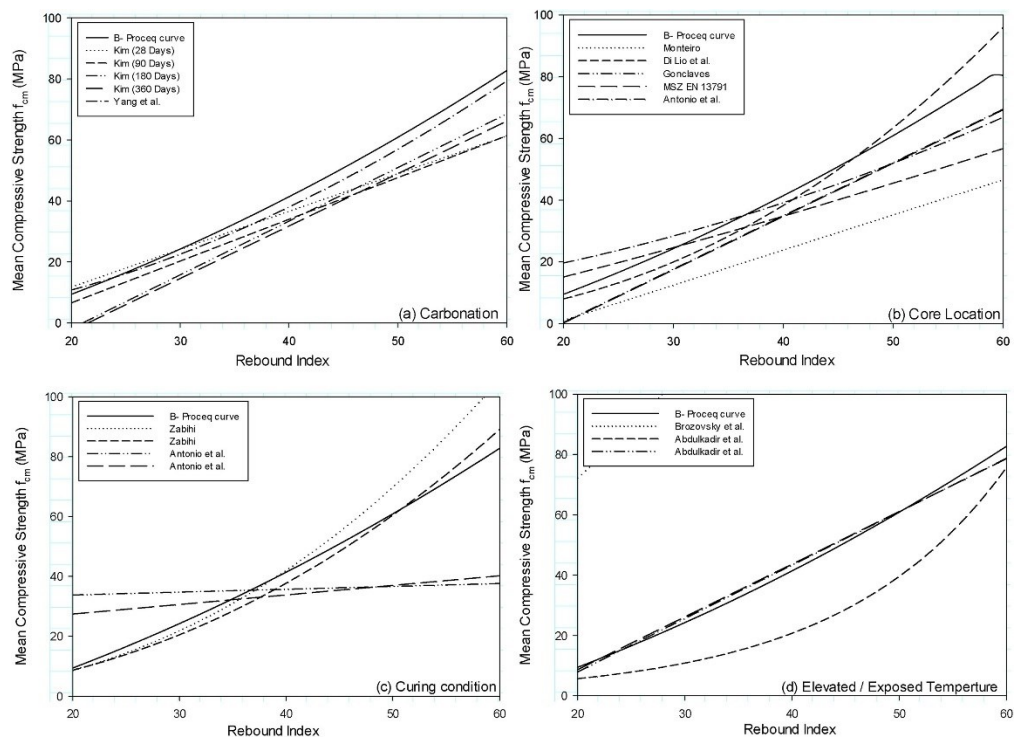


Figure 2.1-5 Rebound index vs. compressive strength relationship curves proposed by different authors considering influencing factors. (Kumavat et al., 2021)

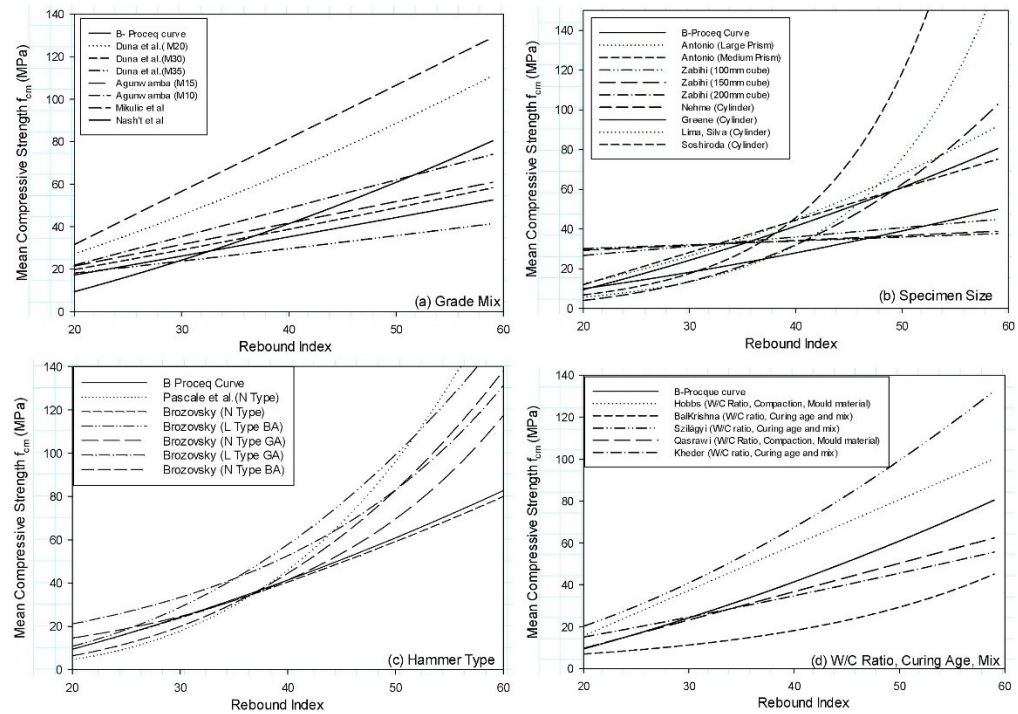


Figure 2.1-6 Rebound index vs. compressive strength relationship curves proposed by different authors considering influencing factors. (Kumavat et al., 2021)

Table 2.1-1 Statistical relationships between compressive strength of concrete (f_{cm}) and rebound number (R). (Kumavat et al., 2021)

Authors	Influencing factors (Boundary conditions)	Equations	Regression Approach
Proceq (2003) [42]	Original Schmidt hammer	$f_{cm} = 0.0117.R^2 + 0.8973.R - 13.213$	Poly.
Kheder (1999) [43]	W/C ratio, Curing age and concrete mix	$f_{cm} = 0.403.R^{1.2083}$	Power
Balkrishna et al. (2017) [44]		$f_{cm} = 2.6723e^{0.0479R}$	Power
Szilágyi et al. (2015) [45]		$f_{cm} = 11.04 \times 10^{-2}.R^{1.739}$	Power
Qasrawi (2000) [46]	W/C Ratio, Compaction, Mold material effect (0.50, vibration, cube 150 mm)	$f_{cm} = 1.353.R - 17.393$	Linear
Hobbs and Kebir (2006) [47]	W/C Ratio, Compaction	$f_{cm} = 2.1683.R - 27.747$	Linear
Pascale et al. (2003) [48]	Types of hammers used	$f_{cm} = 0.0002392R^{3.299}$	Power
Brozovsky and Bodnarova	(N type hammer)	$f_{cm} = 0.0107R^2 + 0.9073R - 12.935$	Poly.

(2016) [32]	(CSN EN 13791)	$f_{cm} = 1.73R - 34.5$	Linear
Brozovsky (2014) [49]	Types of hammers and aggregate		
	(N type, Granodiorite aggregate)	$f_{cm} = 5.1523 e^{0.0521 R}$	Power
	(L type, Granodiorite aggregate)	$f_{cm} = 8.5006 e^{0.0456 R}$	Power
	(N type, Basalt aggregate)	$f_{cm} = 0.0015 R^{2.7916}$	Power
	(L type, Basalt aggregate)	$f_{cm} = 0.0076 R^{2.4229}$	Power
Kim et al. (2009) [18]	Carbonation effect in days	—	
	(28 days)	$f_{cm} = 1.24R - 13$	Linear
	(90 days)	$f_{cm} = 1.37R - 20.8$	Linear
	(180 days)	$f_{cm} = 1.76R - 37$	Linear
	(360 days)	$f_{cm} = 1.72R - 37$	Linear
Yang et al. (2018) [17]	Carbonation depth (dm) is 6 mm for 28 days and w/c ratio- 0.58)	$f_{cm} = 0.05853.R^{1.814985} \cdot 10^{-0.0475dm}$	Power
Monteiro and Goncalves (2009) [25]	Influence of Core specimen	$f_{cm} = 1.14R - 21.8$	Linear
Di Leo et al. (1984) [50]		$f_{cm} = 0.00883.R^{2.27}$	Power
Antonio et al. (2013) [51]		$f_{cm} = 0.0103.R^2 + 0.3586.R + 8.2986$	Poly.
Goncalves (1995) [52]		$f_{cm} = 1.73.R - 34.3$	Linear
EN 13791 (2007) [40]		$f_{cm} = 1.73.R - 34.5$	Linear
Aydin and Saribiyik (2010) [53]	Influence of Curing age		
	28 days	$f_{cm} = 11.612R - 52.033$	Linear
	90 days	$f_{cm} = 11.674R - 238.31$	Linear
Antonio et al. (2013) [51]	Curing age (28–100 days)	$f_{cm} = e^{0.1264R}$	Power
	Influence of curing condition (All grade mix)		
	(Cooled in air- 28 days)	$f_{cm} = 0.0096.R^{2.273}$	Power
	(Cooled in water - 28 days)	$f_{cm} = 0.0152.R^{2.119}$	Power
Zabihi (2012) [54]	(Cooled in air - 28 days)	$f_{cm} = 0.0953.R + 31.887$	Linear
	(Cooled in water - 28 days)	$f_{cm} = 0.3187.R + 21.055$	Linear
Antonio et al. (2013) [51]	Influence of moisture condition		
	(Dry concrete)	$f_{cm} = 1.2183.R^{0.1071R}$	Power
	(Wet concrete)	$f_{cm} = 0.038.R^{1.8889}$	Power
	Influence of stress state		
	(0 MPa)	$f_{cm} = e^{0.0955R}$	Power
	(5 MPa)	$f_{cm} = e^{0.0871R}$	Power
	(10 MPa)	$f_{cm} = e^{0.0875R}$	Power
	Influence of specimen shape (Prism Size, curing days))		
	(320 × 800 × 1200 mm - 28 days)	$f_{cm} = e^{0.0865R}$	Power
	(250 × 250 × 500 mm - 28 days)	$f_{cm} = e^{0.0955R}$	Power
Zabihi (2012) [54]	(100 mm cube - 28 days)	$f_{cm} = 0.4658.R + 17.326$	Linear
	(150 mm cube - 28 days)	$f_{cm} = 0.2461.R + 24.337$	Linear
	(200 mm cube - 28 days)	$f_{cm} = 0.1951.R + 26.149$	Linear

Nehme (2004) [55]	Cylinder (150 × 300 mm-28 days)	$f_{cm} = 0.0005R^3$	Power
Greene (1954) [08]		$f_{cm} = 0.1134 \cdot R^{1.4927}$	Power
Malhotra and Carino (2004) [24]		$f_{cm} = 54.1 \cdot \ln R - 148.4$	Expo.
Lima and Silva (2000) [56]		$f_{cm} = 0.0501 \cdot R^{1.8428}$	Power
Soshiroda et al. (2006) [57]		$f_{cm} = 1.623 \cdot R - 20.547$	Linear
Duna et al. (2014) [58]	Influence of grade of concrete		
	(M 20)	$f_{cm} = -0.011R^2 + 1.282R - 2.844$	Poly.
	(M 30)	$f_{cm} = -0.002R^2 + 0.829R + 2.422$	Poly.
	(M 35)	$f_{cm} = 0.001R^2 + 0.519R + 7.343$	Poly.
Aguwamba and Adagba (2012) [59]	Influence of grade of concrete		
	(1:2:4)	$f_{cm} = 1.012 \cdot R + 1.218$	Linear
	(1:3:6)	$f_{cm} = 1.339 \cdot R - 4.878$	Linear
Mikulic et al. (1992) [60]	Grade of concrete (M20 to M35)	$f_{cm} = 2.50 \cdot R - 18.4$	Power
Nash't et al. (2005) [61]	Cement type, Grade	$f_{cm} = 0.788R^{1.03}$	Power
Brozovsky and Bodnarova (2016) [32]	Effect of elevated temperature		
	(Before heat load 0°C)	$f_{cm} = 0.0425 \cdot R^2 + 1.4965 \cdot R + 25.294$	Poly.
	(After heat load 200°C to 800°C)	$f_{cm} = 1.55e^{0.0648R}$	Power
Abdulkadir et al. (2017) [63]	Effect of exposed to fire		
	(All mixes cooled in air)	$f_{cm} = 1.773R - 27.58$	Linear
	(All mixes cooled in water)	$f_{cm} = 1.75R - 26.357$	Linear
Miscellaneous influencing factors			
Kolek (1958) [64]	Cube specimen from sites	$f_{cm} = 0.056 \cdot R^2 - 0.022 \cdot R + 1.57$	Poly.
Shariati et al. (2011) [65]	Existing building	$f_{cm} = 1.7206R - 26.595$	Linear
Hajjeh (2012) [66]	(Hammer horizontal position)	$f_{cm} = 1.0501 \cdot R - 11.8402$	Linear
	(Hammer vertical position)	$f_{cm} = 0.9888 \cdot R - 14.2361$	Linear
Pascale et al. (2000) [67]	(Effect of high strength concrete)	$f_{cm} = 0.000135R^{3.4424}$	Power

Nondestructive test (NDT) methods and sensor technologies are evaluated in the context of providing input parameters to service life prediction models for reinforced concrete structures. Relevant NDT methods and sensors

are identified that are based on diverse technologies including mechanical impact, ultrasonic waves, electromagnetic waves, nuclear, and chemical and electrical methods. The degradation scenarios of reinforcement corrosion, alkali-silica reaction, and cracking are used to identify gaps in available NDT methods for supporting condition assessment and service life prediction. Common gaps are identified, along with strategies for resolving those gaps.(Snyder et al., 2013)

Analyzing the obtained results, some important conclusion can be defined:

- _ The present study confirmed the possibility of using NDUPVM for the assessment of reinforced concrete structures and the possibility for obtaining information about the homogeneity of the reinforced concrete, for detection of caverns and cracks, and assessment of the quality of the construction.

- _ Measuring, processing, analyzing, and interpreting the obtained results required careful data collection, high qualification of the researchers, and expert analysis.

- _ All measured crack depths by the NDUPVM were smaller than the real ones.

- _ This research confirmed that the visually determined crack depths were greater than those determined by the NDUPVM.

- _ The direct exposure on external atmospheric impacts, such as rain, snow, etc. had an influence on the accuracy of the NDUPVM measurements.

- _ The relative error ε_c varied in a wide range, between 0.97% and

61.67%, and it was not possible to predict the real value of crack depth only by NDUPVM in the case of direct exposure of external atmospheric impacts over the examined structures.

_ Further research is required to systematize the methods for detecting defects and cracks in reinforced concrete.

_ It is necessary to extend the research on beams with different shape, reinforcement ratio, concrete grade, etc., and on other structural elements, like slabs, columns, walls, etc.(Ivanchev & Slavchev, 2019)

This work aims to study the influence that certain technological variables have on the results obtained through the UPV. Two concrete elements were cast at the laboratory. One element with reinforcement and another without reinforcement.

Inside these elements were introduced objects to reproduce possible concrete damages. To facilitate the analysis the results are represent through several images generated by an image software and a statistical analysis software. This study confirm that the correct choice of test parameters is crucial to have a right interpretation.(Adamatti et al., 2017)

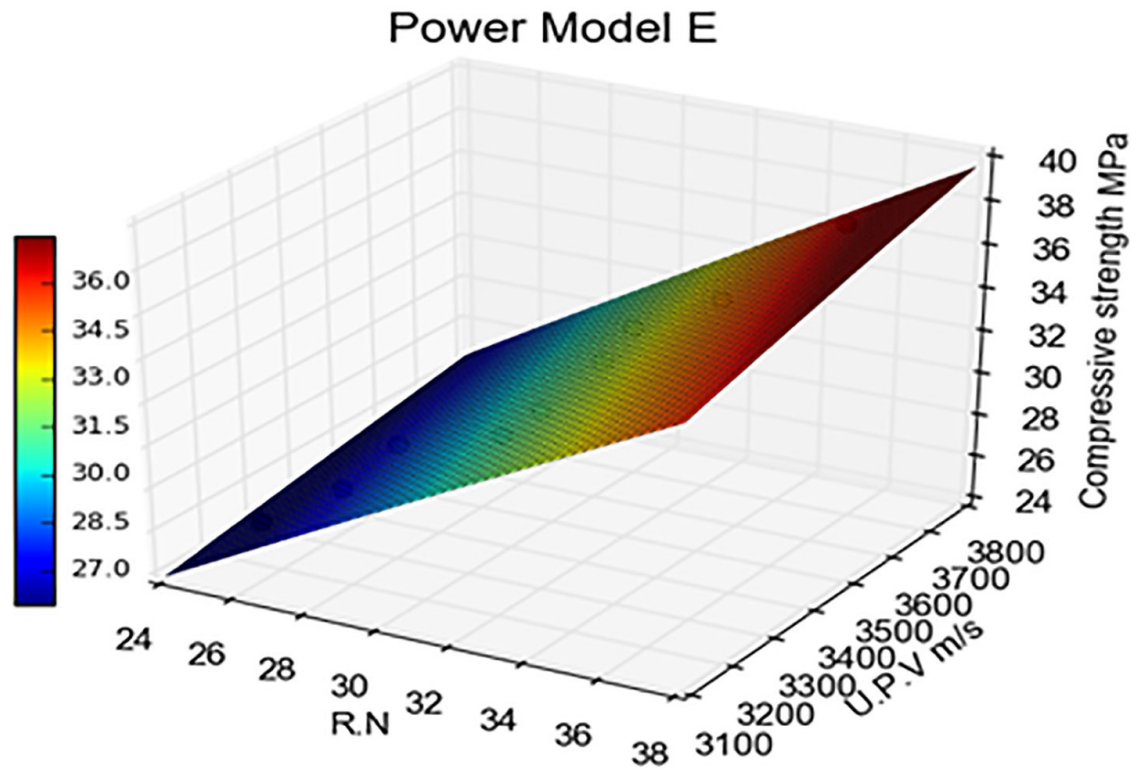


Figure 2.1-7 Relationship between compressive strength test and N.D.T for metakaolin geopolymer concrete.(Noori et al., 2021)

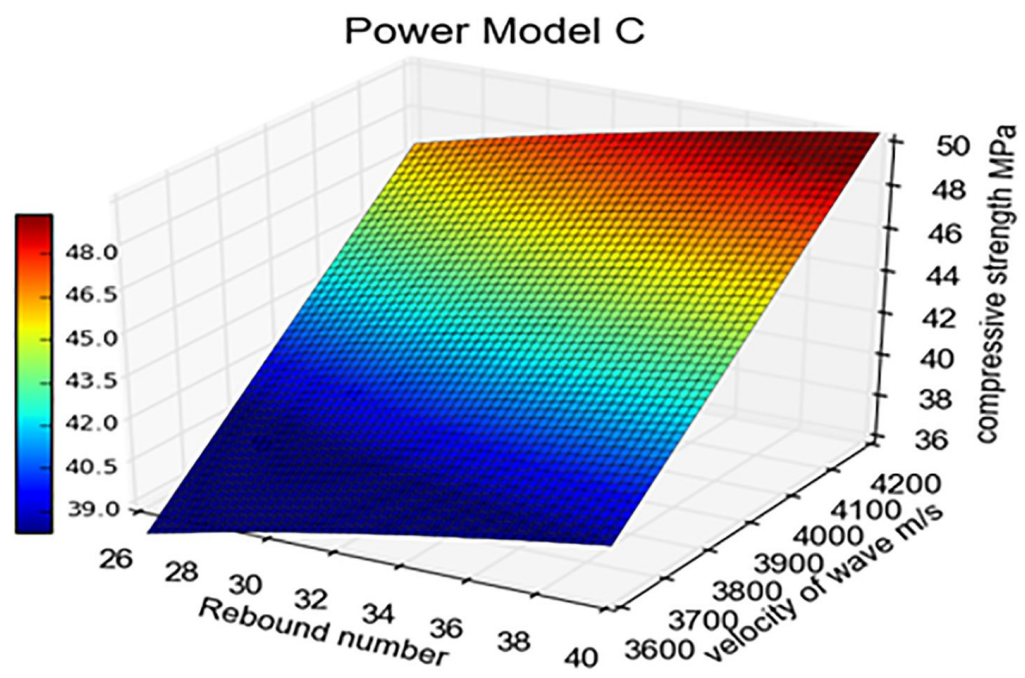


Figure 2.1-8 The relationship between compressive strength test and N.D.T for fly ash geopolymer concrete. (Noori et al., 2021)

Fly ash-based geopolymer concrete has a higher compressive strength than metakaolin -based geopolymer concrete. The higher compressive strength was attributed to the higher silica content, resulting in better binding properties between particles. The effect of NaOH concentration is apparent on both compressive strength and N.D.T for geopolymer concrete. Increasing the molarity from 8 to 12 and then to 16 M shows a significant increase in compressive strength due to enhancement in the geo-polymerizations process.

Increasing the amount of source material from 400 to Kg/m³ leads to a specific improvement in compressive strength, UPV, and rebound number due to an increase in Si and Al amount. From experimental results of compressive strength and N.D.T (U.P.V and R.N), equations can be made to estimate compressive strength from N.D.T for both types of geopolymer concrete with reasonable accuracy. (Noori et al., 2021)

This literature review provided a comprehensive overview of the state-of-the-art in stress wave-based NDT for SCCSs. Multiscale numerical simulation and multi-physics coupling analysis, which help guide the understanding of wave propagation, damage detection mechanisms, experimental design, and sensor selection, were summarized in-depth. According to the research findings from the experimental and numerical studies described in current literatures, including the authors own studies, the main conclusions can be made as follows:

- (1) Wave propagation analysis in SCCS cannot be accurately simulated

using the homogeneous material assumption. The mesostructure of concrete needs to be considered to improve simulation accuracy. The use of mesoscale models composed of various aggregate samples with different geometries and distribution patterns is suggested in mesoscale simulation. For cases involving high-frequency excitation, the ITZ should be considered in mesoscale modeling.

(2) Simulated stress wave fields excited by point loading and by PZT actuators are slightly different. Multi-physical coupling models are preferred to investigate the mechanism of wave propagation in SCCS.

(3) The computational cost of FEM-based multi-physics coupling analysis at the *meso*-level is excessive. Advanced SEM approach can efficiently improve the computational speed. Moreover, multiscale modeling is suggested to accelerate multi-physics coupling analysis.

(4) Three-dimensional simulations are more accurate than 2D numerical analysis. Symmetry constraints, artificial damping, infinite elements, low reflection boundaries, absorbing layers with increasing damping (ALID), and combinations of the above are beneficial for reducing the computational cost of 3D simulations, especially for multi-physical coupling analysis at the *meso*-level.(Chen et al., 2021)

Table 2.1-2 Mean values of the experimentally obtained and theoretically calculated modulus of elasticity of concrete and the relative error for each of the days.(Ivanchev, 2018)

Age of	Modulus of elasticity	Error
--------	-----------------------	-------

concrete	EN 12504-4	EN 12390-13	EN 1992 1-1	EN 12504-4	EN 12390-13
[Days]	[MPa]	[MPa]	[MPa]	[%]	[%]
3	22418.69	-	26572.13	15.6	-
7	25481.32	-	28760.11	11.4	-
14	26226.98	-	30051.79	12.7	-
28	32916.24	28033.3	31000.00	6.2	9.6
244	34825.82	28809.1	32576.11	6.9	11.6
280	35496.71	28902.4	32631.19	8.8	11.4
293	35640.51	29022.5	32648.56	9.2	11.1
342	35936.99	29160.4	32704.93	9.9	10.8
1126	36547.68	29208	33021.48	10.7	11.5

2.1.1 Structured

(Amini et al., 2016) found that UPV and RH should be used in combination in a quadratic polynomial model structure. Therefore, the final model was proposed based on combining models from a threefold cross-validation of the experimental data. This model predicted the independent data with very good accuracy.

(Latif Al-Mufti & Fried, 2012) established that UPV measurements can be used to determine concrete setting. Concrete setting is the time that it would take for concrete to fully harden.

2.2 Neural network

(Schmidhuber, 2015) Has shown that artificial neural networks are useful as a method for synthesizing a result from data.

2.3 MATLAB

(Al Shamisi et al., 2011) Has shown that MATLAB is useful as a method

for easily synthesizing insights. A neural network needs inputs to produce an output.

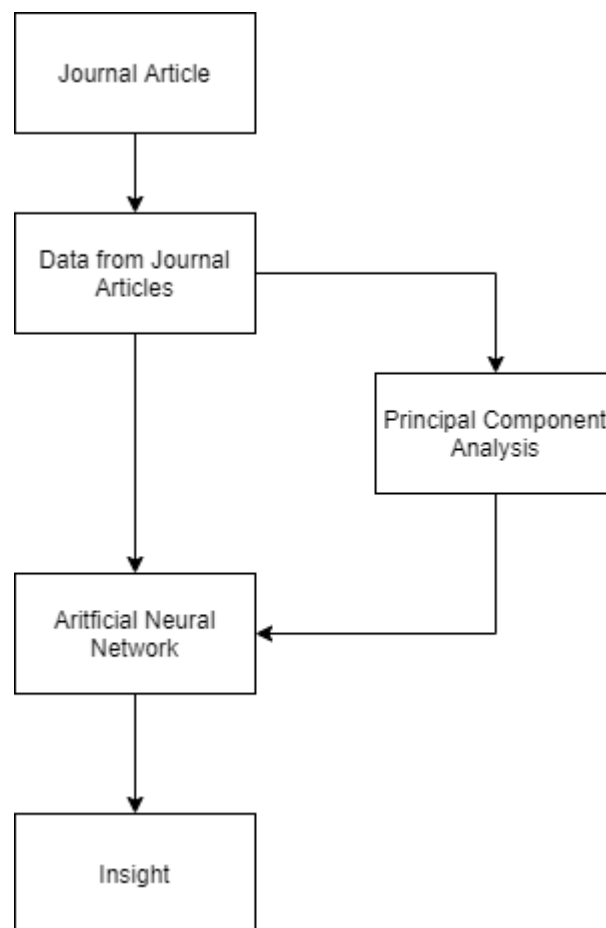
2.4 PCA

(Mohamad-Saleh & Hoyle, 2008) Has shown that using Principal Component Analysis (PCA) improves the performance of a neural network.

CHAPTER III

Framework

3.1 Conceptual Framework



Conceptual Framework

From the journal article, the data from those journal articles would be extracted. Then either the data would go to the artificial neural network (ANN)

directly or would be analyzed by principal component analysis then go to the ANN. The process expects to give an insight with regards to how the parameters of its creation would change the compressive strength of the concrete.

3.2 Theoretical Framework

3.1.1 Artificial neural network

The study will use an Artificial Neural Network (ANN) to model the compressive strength. The idea would be to leverage the currently existing literature on the internet to perform the technique. Data could be found by asking or by leveraging graphs provided in the journals.

An ANN is based on a collection of connected units or nodes called artificial neurons, which loosely model the neurons in a biological brain. Each connection, like the synapses in a biological brain, can transmit a signal to other neurons. An artificial neuron that receives a signal then processes it and can signal neurons connected to it. The "signal" at a connection is a real number, and the output of each neuron is computed by some non-linear function of the sum of its inputs. The connections are called *edges*. Neurons and edges typically have a *weight* that adjusts as learning proceeds. The weight increases or decreases the strength of the signal at a connection. Neurons may have a threshold such that a signal is sent only if the aggregate signal crosses that threshold. Typically, neurons are aggregated into layers. Different layers may perform different transformations on their inputs. Signals travel from the first layer (the input layer) to the last layer (the output layer), possibly after traversing

the layers multiple times. (Schmidhuber, 2015)

3.1.2 *Ultrasonic Pulse Velocity Test*

An ultrasonic pulse velocity (UPV) test is an in-situ, nondestructive test to check the quality of concrete. In this test, the strength and quality of concrete is assessed by measuring the velocity of an ultrasonic pulse passing through a concrete structure.

This test is conducted by passing a pulse of ultrasonic through concrete to be tested and measuring the time taken by pulse to get through the structure. Higher velocities indicate good quality and continuity of the material, while slower velocities may indicate concrete with many cracks or voids.

Ultrasonic testing equipment includes a pulse generation circuit, consisting of electronic circuit for generating pulses and a transducer for transforming electronic pulse into mechanical pulse having an oscillation frequency in range of 40 kHz to 50 kHz, and a pulse reception circuit that receives the signal. (Amini et al., 2016)

3.1.3 *Rebound Number*

Rebound Hammer test is a Non-destructive testing method of concrete which provide a convenient and rapid indication of the compressive strength of the concrete. The rebound hammer is also called as Schmidt hammer that consist of a spring-controlled mass that slides on a plunger within a tubular housing. When the plunger of rebound hammer is pressed against the surface of concrete, a spring-controlled mass with a constant energy is made to hit concrete surface to rebound back. The extent of rebound, which is a measure of surface hardness, is measured on a graduated scale. This measured value is designated as Rebound Number (rebound index). Concrete with low strength

and low stiffness will absorb more energy to yield in a lower rebound value.

(Szilagyi & Borosnyoi, 2009)

CHAPTER IV

Research Methodology

4.1 Research Method

The research method that would be used is historical method.

The research would be done by using MATLAB to process the data. Web Plot Digitizer would be used to convert the points in the charts into tabular data.

The data would come from journals and other reliable sources.

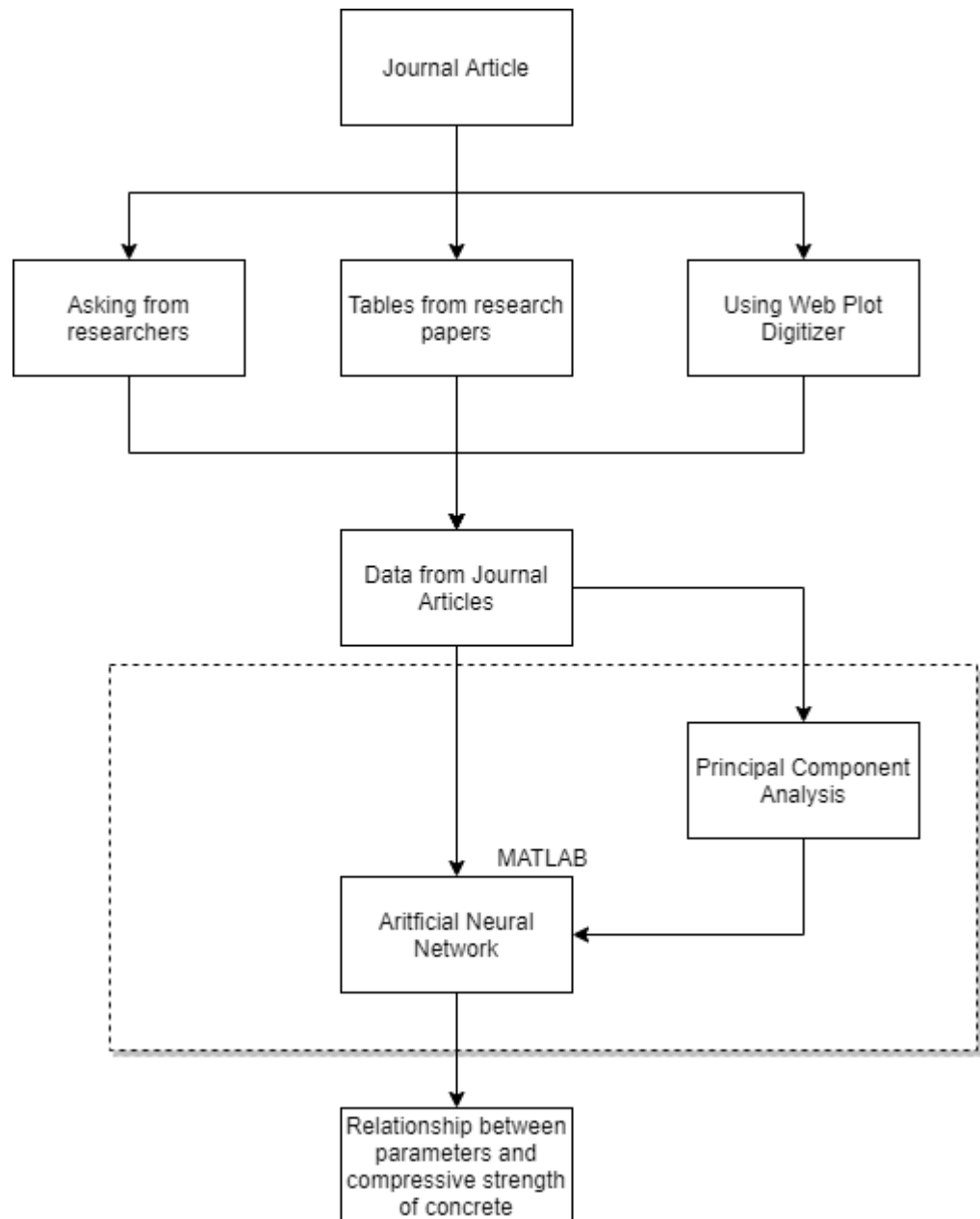
4.2 Research Design

The data would be the previous research in the field of non-destructive testing that tries to find out the compressive strength of a concrete using non-destructive methods.

4.3 Data Cleansing

The graph that would be placed on Web Plot Digitizer would be cleaned by removing formulas in the pictures of charts. Outrageous values from the same program would also be removed. Visual inspection will be used to filter out discrepant points.

4.4 Summary of Procedures



Summary of research

The flow of the study begins by looking at the different journal articles. The data from the articles could be sourced by asking the authors, using tables of the data, if available, or by using web plot digitizer.

Then afterwards, the data could be either analyzed directly using the artificial neural network or by using principal component analysis and then using the most significant variables (as found by principal component analysis) into the artificial neural network. The flow is expected to find the relation between the compressive strength of concrete and the different parameters that influence its creation.

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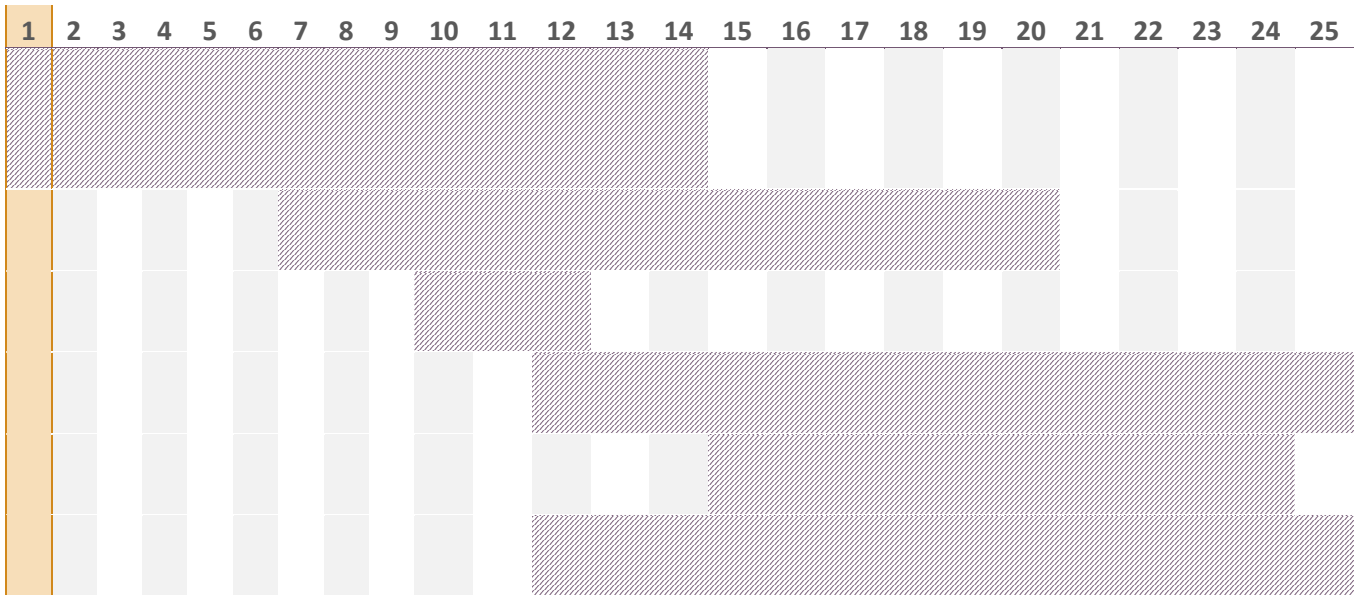
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APPENDIX A: Gantt Chart

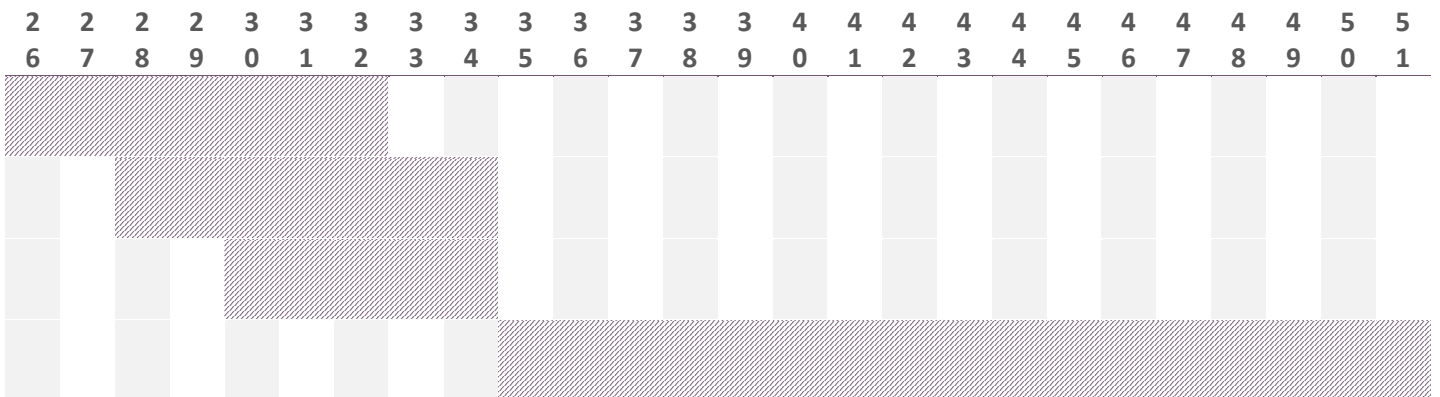
Gantt Chart Tentative Activities

ACTIVITY	PLAN START	PLAN DURATION
Gathering Factors that influence the Compressive Strength of Concrete	1	14
Data Gathering	7	14
Initial ANN attempt	10	3
Diagnosing errors with ANN usage	12	14
Reworking manuscript based on new knowledge on ANN	15	10
Principal Component analysis	12	14
Analysis using ANN	25	8

Data and results writeup	28	7
Conclusion Writeup	30	5
Finishing of manuscript	35	17



Preliminary Gantt Chart Part 1



Preliminary Gantt Chart Part 2

The two Gantt Chart shows a rough sketch of how the activities would be separated. It should be noted however, that the Gantt Chart is only an approximation since there is no information yet on the school days that would be encompassed by term 1 and 2, AY2021-2022.

Another consideration is that it might be possible to use the vacation days as days to perform work on the thesis.

APPENDIX B: Budgeting

There are no expected budget requirements in performing the thesis. However, MATLAB is not a free software. DLSU offers MATLAB as part of being in the institution.

APPENDIX C: Anticipated Problems

There are no anticipated problems that could not be solved.